Metal-on-Metal Hips:

Device Mechanics and Failure Modes

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Exponent, Inc., and Drexel University

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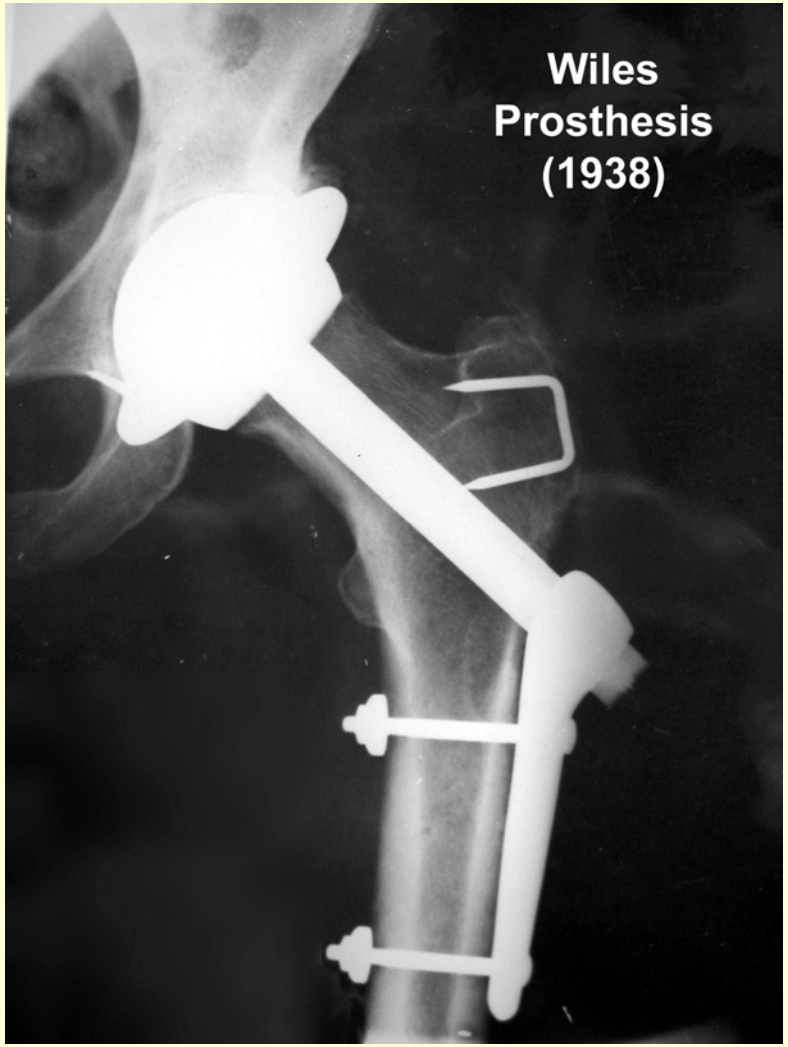
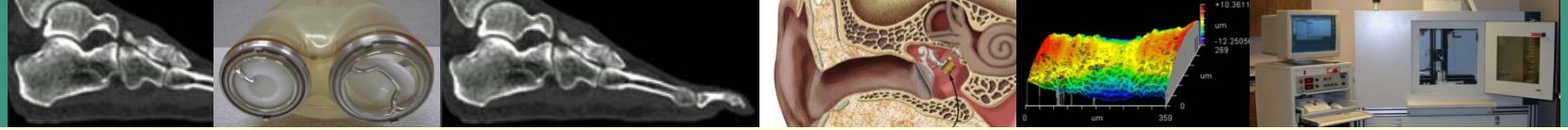
Supported by the

National Institutes of Health

National Institute of Arthritis and Musculoskeletal and Skin Diseases

Early Designs: 1930s-50s

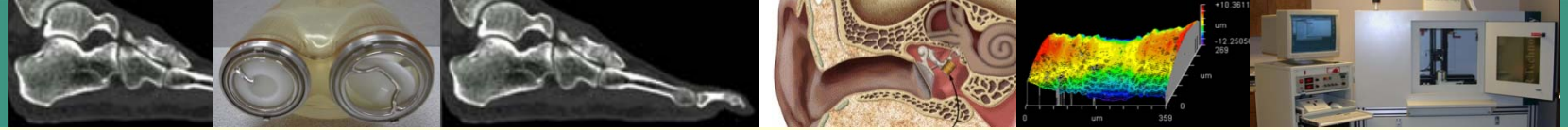




Why Was MOM Abandoned in 1970s?

- Early success of the Charnley prosthesis
- High frictional torque, equatorial binding
- Carcinogenesis concerns
- Metal sensitivity concerns
- High infection rates
- Increased strain rates in periprosthetic trabecular bone

Dowson D and Jin Z-M. “Metal-on-metal hip joint tribology.” Proc. IMechE Part H. 2006 220:107-118

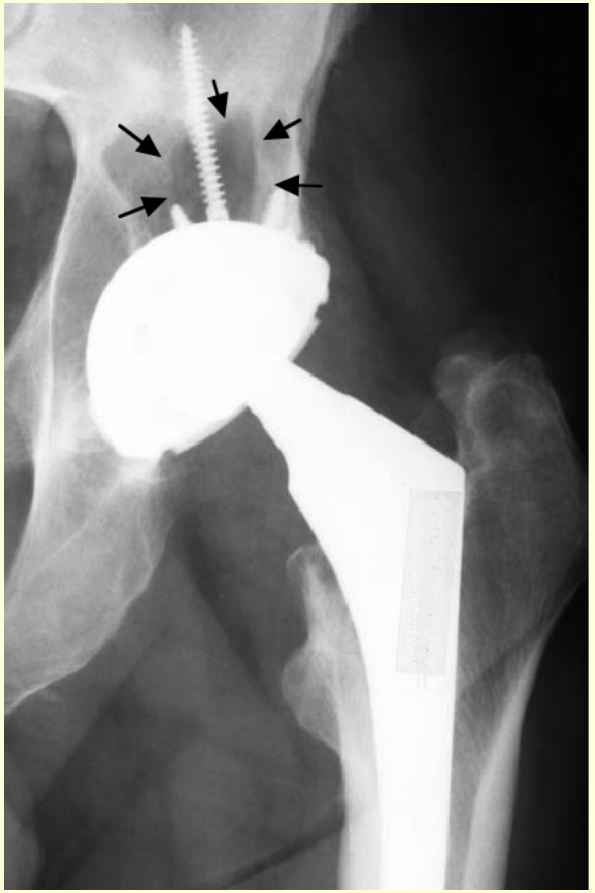


1990s: Gamma Air Polyethylene

By 1990's, MoP bearings dominated THA

But MoP in the 1990's had limitations:

- Gamma irradiation in air
- Oxidation
- Polyethylene wear debris
- Osteolysis
- Management of young, active patients



Low Wear from Some 1st Generation MoM Hips

(McMinn 2006)

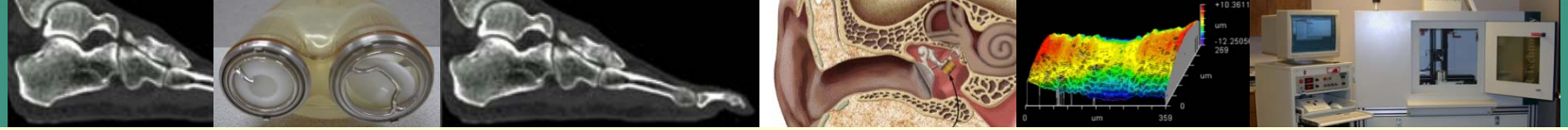
Ring Metal on Metal Total Hip Replacement

Explanted after 23.5 years

Femoral head Wear Rate 0.43 µm/year

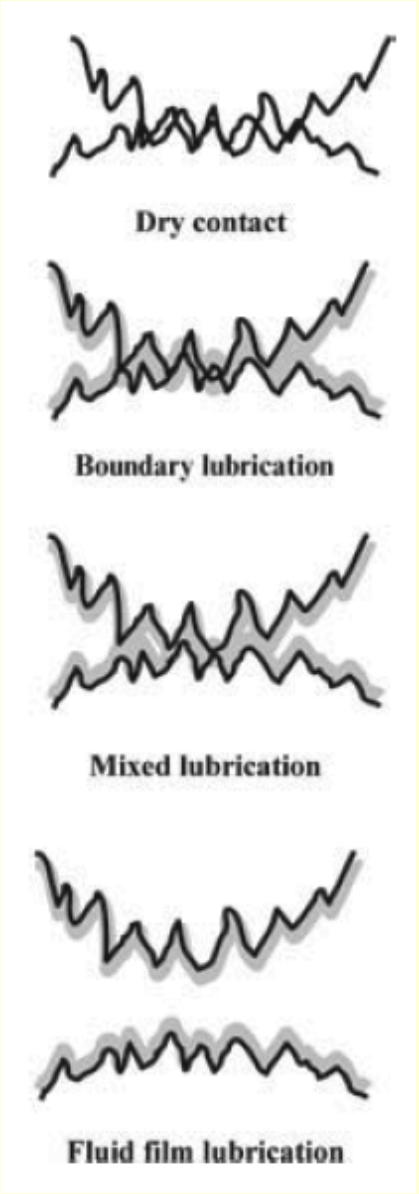
Acetabular cup wear Rate 0.35 µm/year

McMinn, Daniel. “History and modern concepts in surface replacement.” Proc. IMechE Part H. 2006 220:239 - 251



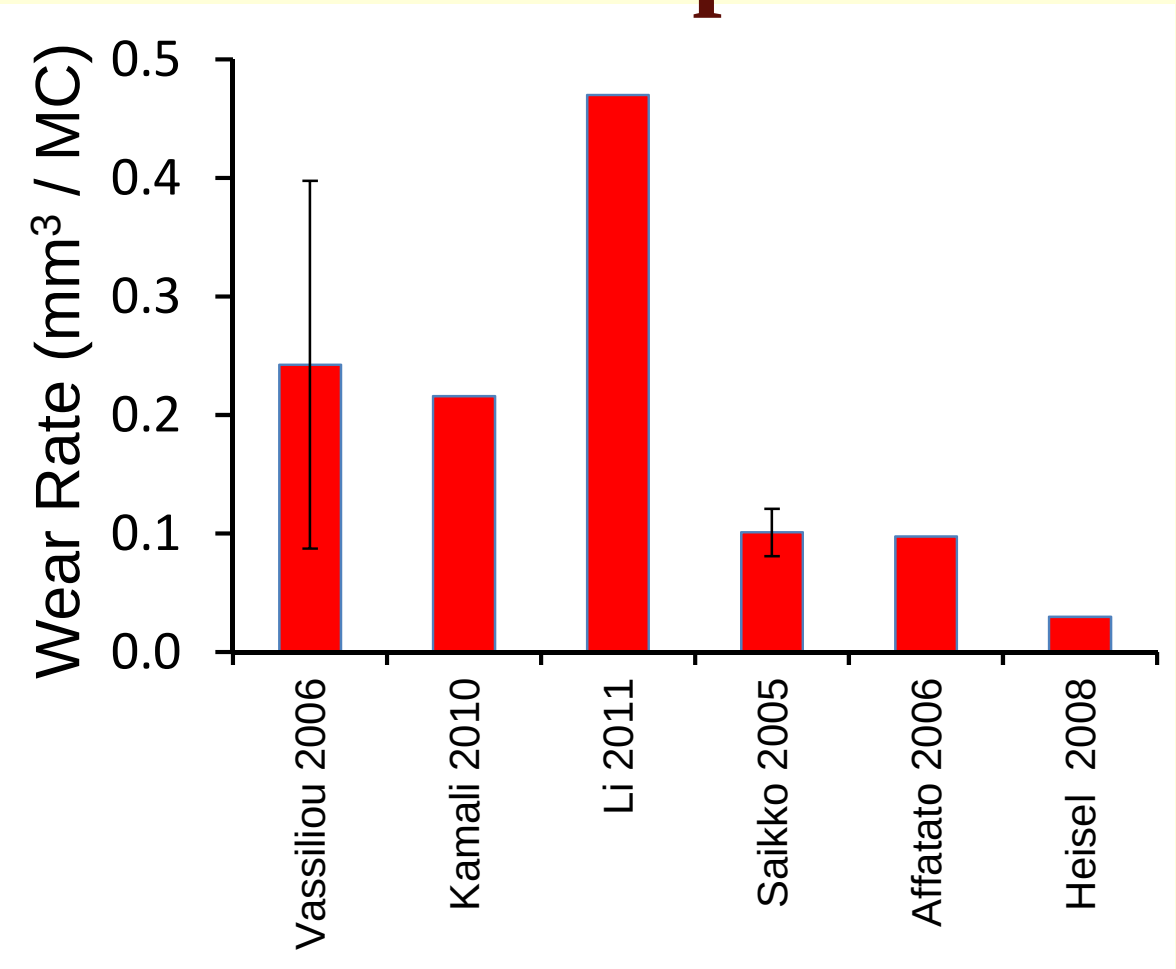
Tribology Theory and MoM Hips

- Theory developed for engine bearings applied to MOM hips in 1980s and 1990s
- Design goal is fluid film lubrication
  - Minimize head-liner clearance, roughness
  - Maximize head diameter
  - “Practically achievable” [1]



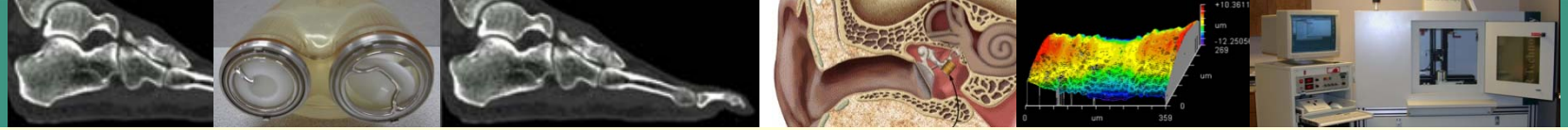
[1]Dowson & Jin. “Metal-on-metal hip joint tribology.” Proc. IMechE Part H. 2008. 220 : 107 - 118

Low Wear Rate in Hip Simulators



- Laboratory testing suggests that MoM hips can achieve “very mild” mixed lubrication[1]

[1]Dowson & Jin. “Metal-on-metal hip joint tribology.” Proc. IMechE Part H. 2008. 220 : 107 - 118



Encouraging Results of “Metasul” MoM Hips

- ~ 300,000 Metasul hips implanted worldwide[1]
- Low wear rates reported for revised hips[2]
- Low Co levels at 5 years[3]
- Encouraging revision rate at 5-11 years[1]

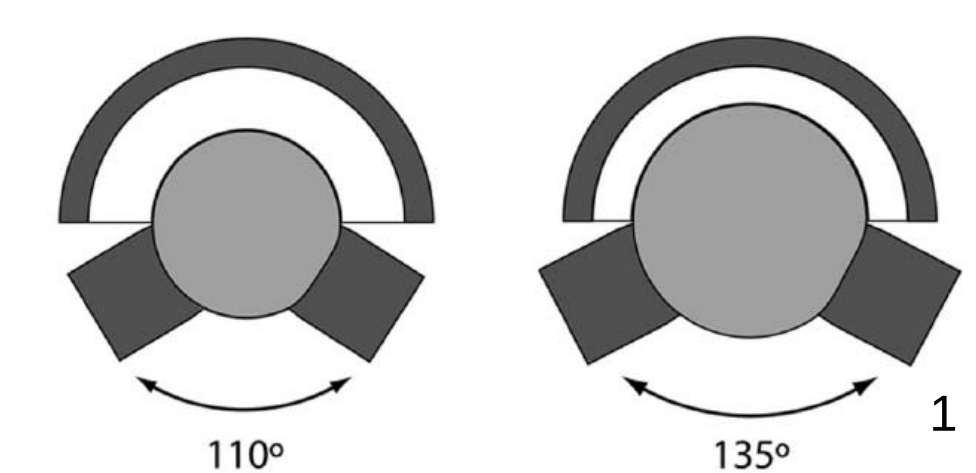
[1]Dorr, Long et al. “The Argument for the Use of Metasul as an Articulation Surface in Total Hip Replacement.” CORR. 2004 429: 80 – 85

[2]Reiker et al. “Development and Validation of a Second-Generation Metal-on-Metal Bearing.” Journal of Arthroplasty 2004 19: 5 – 11

[3]Brodner Bitzan et al. “Serum cobalt levels after metal-on-metal total hip arthroplasty.” JBJS (Am) 2003. 85:2168–2173, 2003

[4]Girard, Bocquet et al. «Metal-on-Metal Hip Arthroplasty in Patients Thirty Years of Age or Younger.” JBJS (Am) 2010; 92:2419-2426

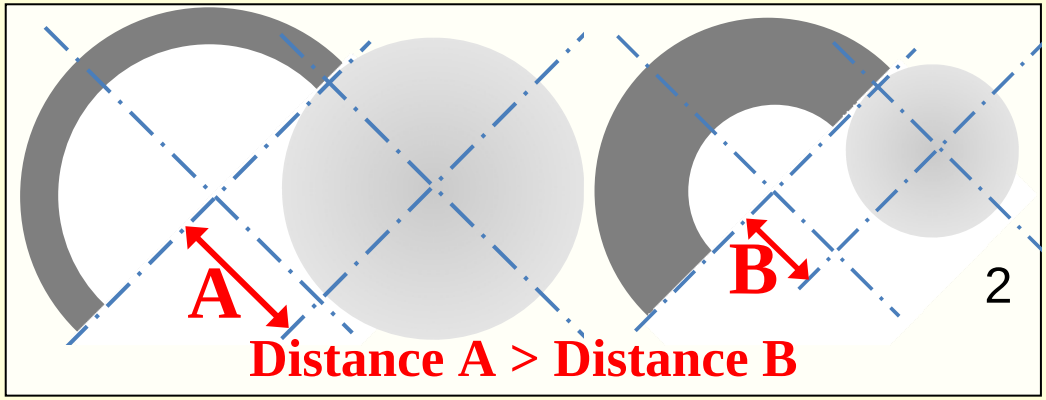
Reduced Risk of Dislocation and Impingement



Large diameter heads:

Increased head neck ratio

Increased range of motion



Increased “jump” distance

Lower risk of dislocation

[1]Malik et al. “Impingement with Total Hip Replacement.” JBJS(Am). 2007;89:1832-42

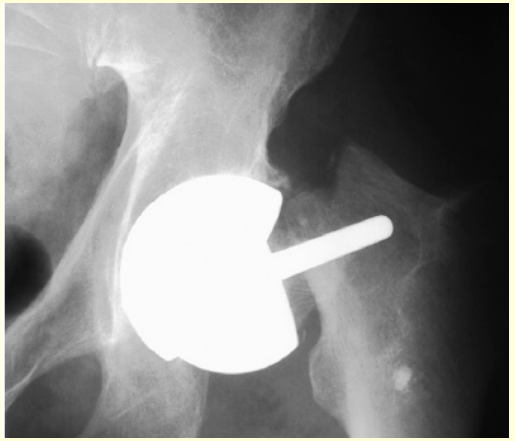
[2]Concept from Saraili et al. “Mathematical evaluation of jumping distance in total hip arthroplasty.” Acta Orthopaedica 2009; 80: 277–282

Clinical Wear and Damage Mechanisms

Femoral Complications (Resurfacing)

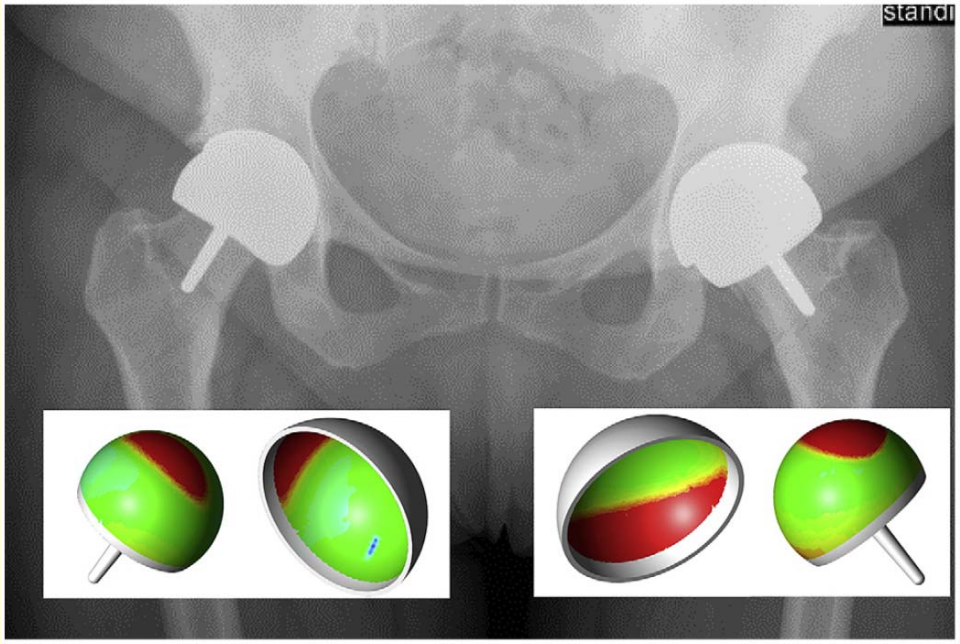
- Femoral neck thinning
- Femoral loosening
- Femoral neck fractures

- Learning curve
- Patient selection



Campbell et al, “A Study of Implant Failure in Metal-on-Metal Surface Arthroplasties,” CORR 453 (2006) 35-46
Shimmin et al, “ Metal on metal hip resurfacing arthroplasty,” JBJS (Am) 2008; 90:637-654

Elevated Wear (Resurfacing, THA)



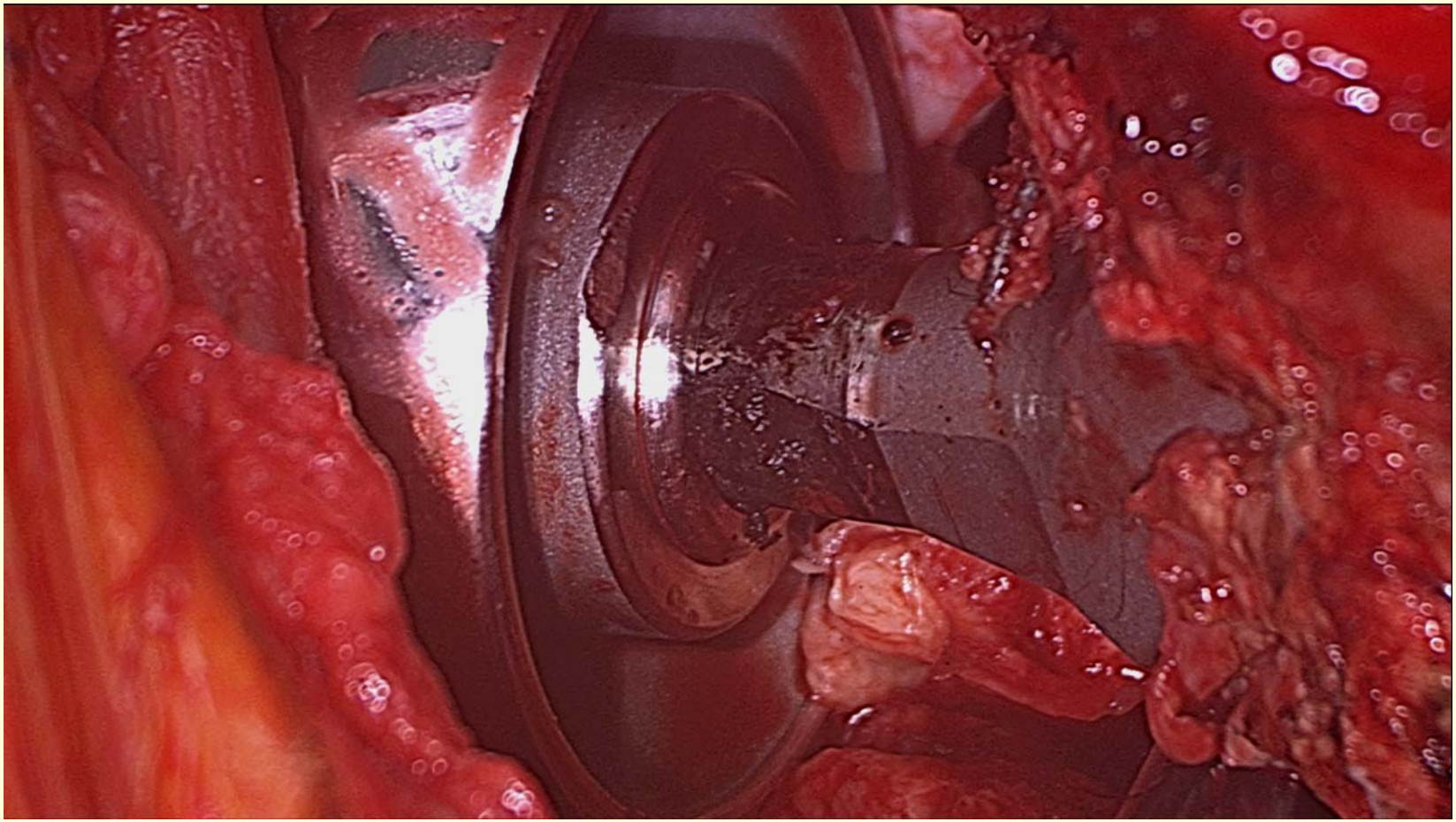
(Langton 2011)

Twin revisions after 19 and 58 months

Evidence of wear on all components

Langton et al, “Reducing Metal Ion Release Following Hip Resurfacing Arthroplasty,” *Orthop Clin N Am 42 (2011) 169–180*.

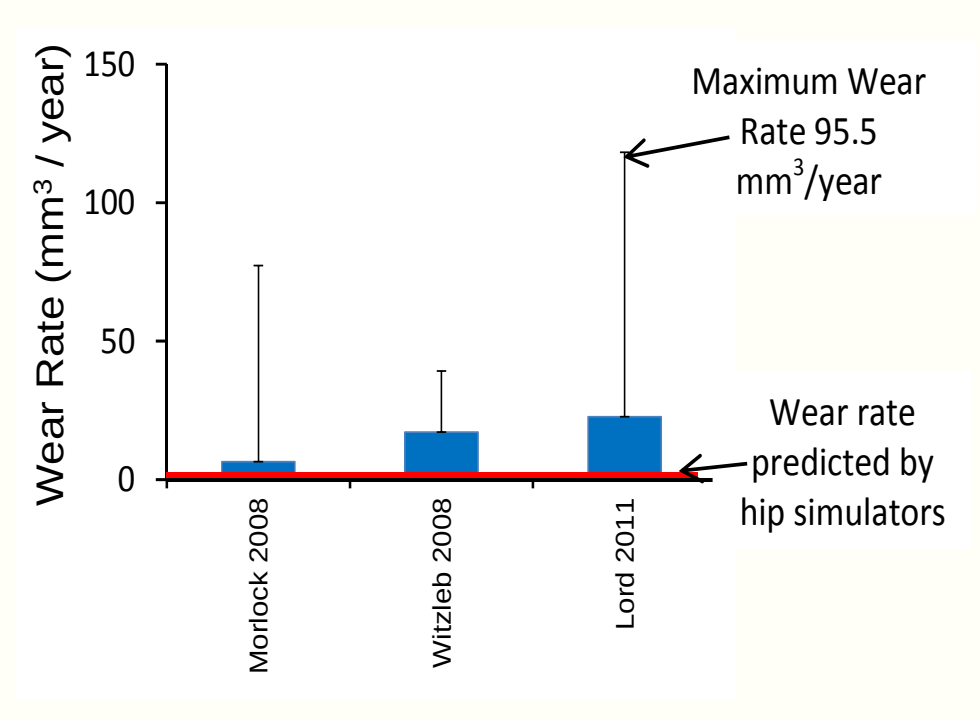
Taper Corrosion, “Trunnionosis” (THA)



Black deposits observed at taper interface during revision

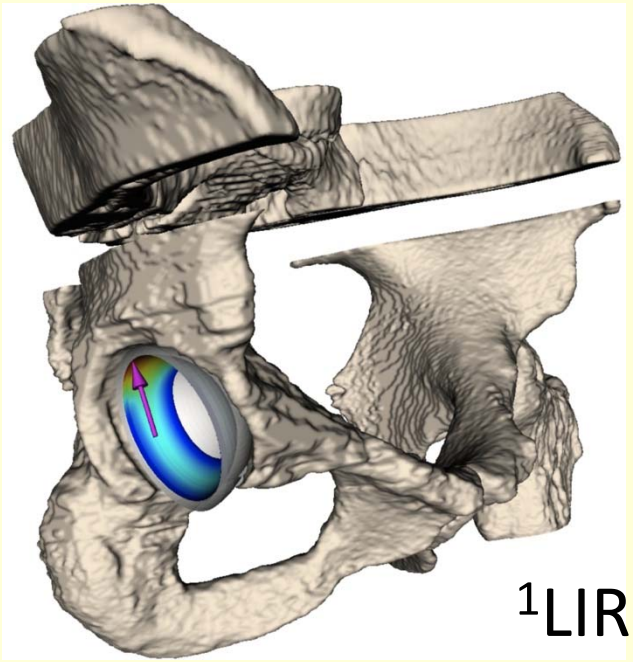
In-vivo vs. In-vitro Wear

- Early revision reportedly linked to elevated wear and inadequate tribology
- Clinical problems are not predicted by simulator tests
- In-vivo wear orders of magnitude higher than in-vitro wear



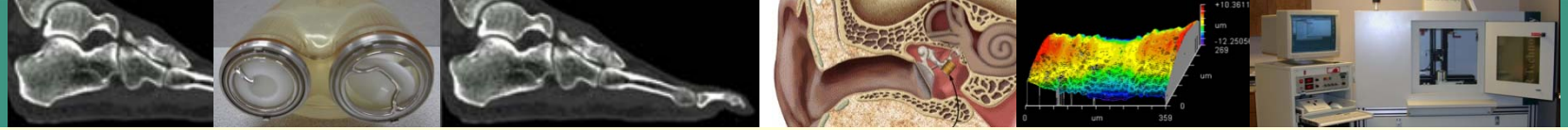
Key Retrieval Issues

- **Articulating Surface Wear**
  - Wear Measurement
  - Standardization at ASTM
  - Edge Wear
  - Contribution to in-vitro testing



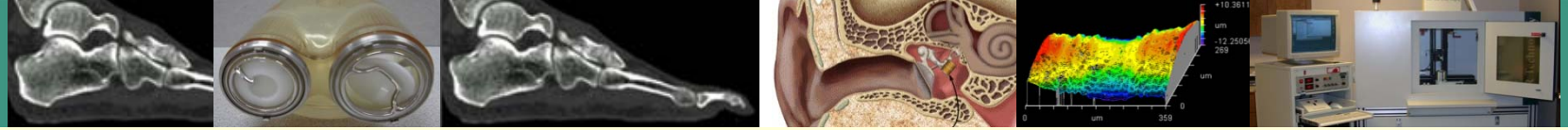
- **Trunnion Tribo-Corrosion**
  - Wear Measurements
  - Wear Mechanisms

[1]www1.imperial.ac.uk/surgeryandcancer/divisionofsurgery/clinical_themes/musculo/retrieval/



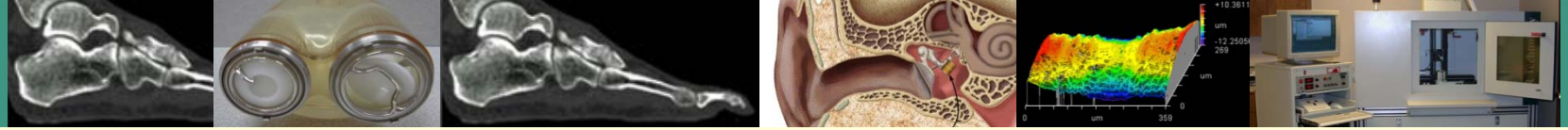
Studies of Bearing Surface Wear

Study	No. of Heads	No. of Cups	Hip System
Underwood 2011	130	130	ASR & BHR
Witzleb 2008	8	2	BHR
Matthies 2011	120	120	BHR, ASR, Adept, Cormet, Durom
Morlock 2008	26	32	
Lord 2011	32	22	ASR
Ebrahzadeh 2011	185	121	BHR, ASR, C+, Cormet, Durom + others
Campbell 2006	66	39	BHR, C+, Cormet, McMinn
Langton 2011	35	35	ASR
Total	602	501	

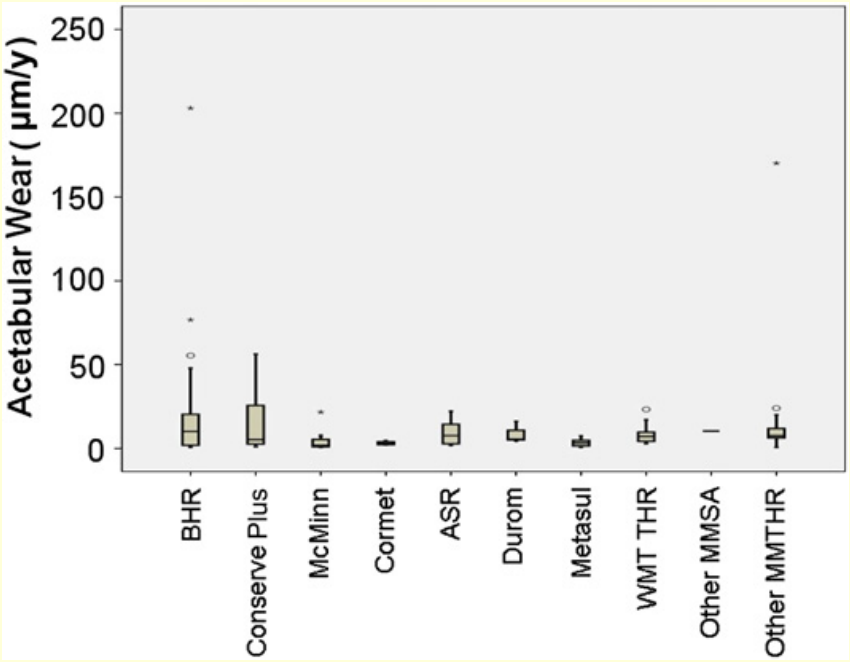


Studies of Bearing Surface Wear

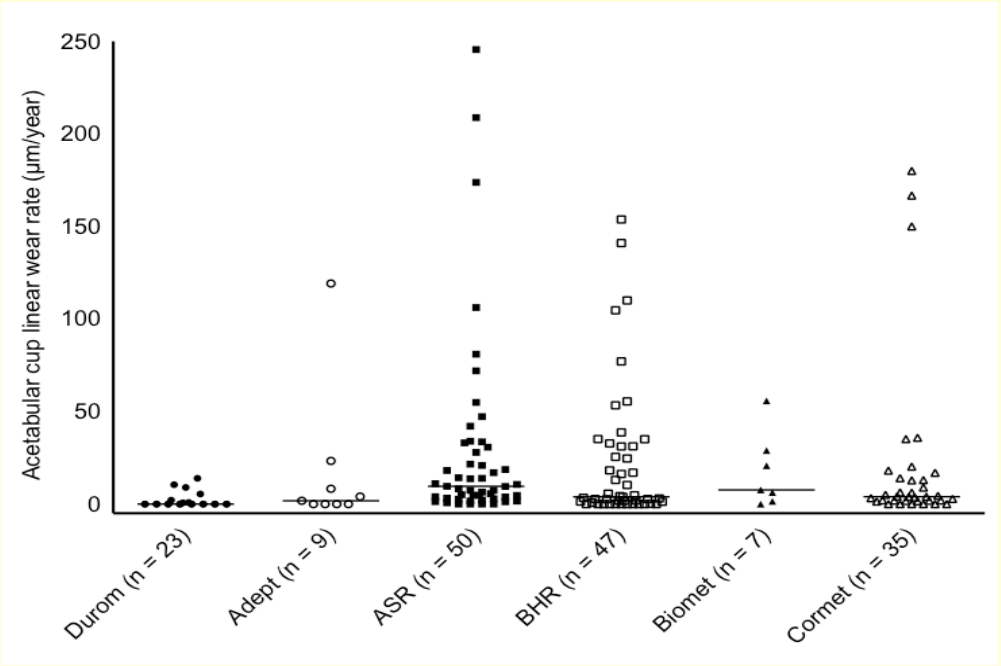
- Limited number of published studies
  - Only ~ 750 unique components
- No standardised measurement and analysis protocol
  - Cannot compare results between studies
  - Standardisation of measurements - ASTM



Retrieval Wear Rates



(Ebramzadeh 2011)

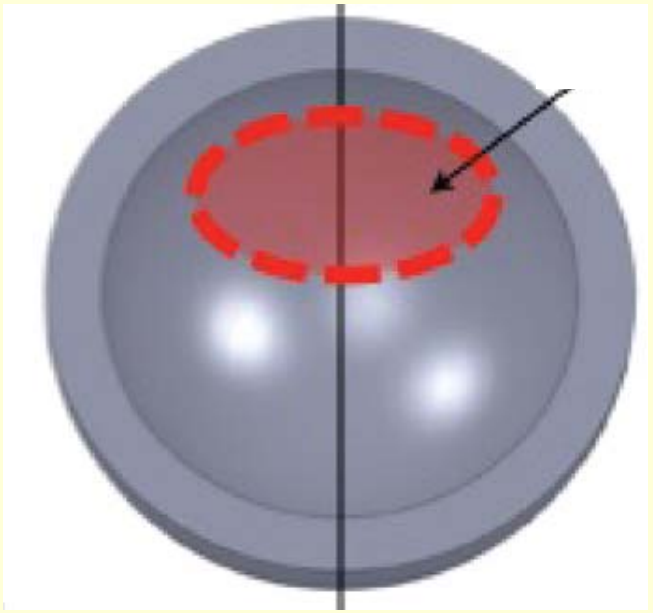


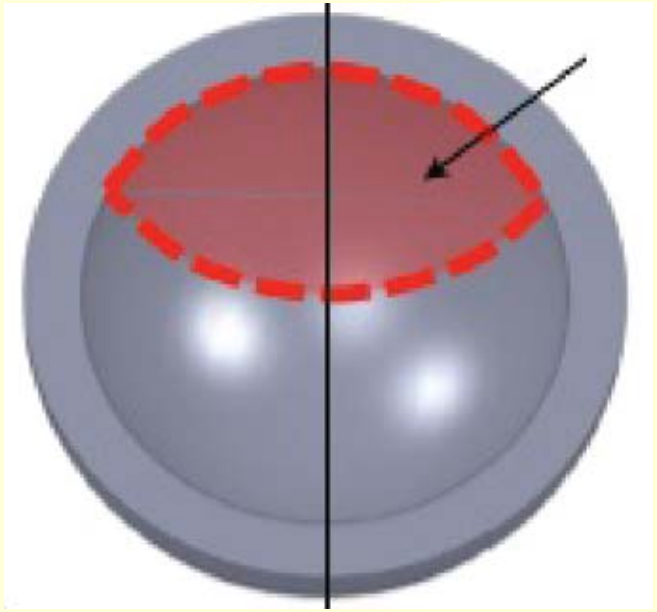
(Hart 2011)

Wide Range of Wear Rates

Ebramzadeh et al, “Failure Modes of 433 Metal-on-Metal Hip Implants: How, Why, and Wear,” Orthop Clin N Am 2011 42: 241–250
Hart et al, “Understanding Why MoM Hip Fail: The London Implant Retrieval Centre,” Scientific Exhibit SE03 AAOS Annual Meeting 2011

Why Simulators Don’t Match the Retrievals?

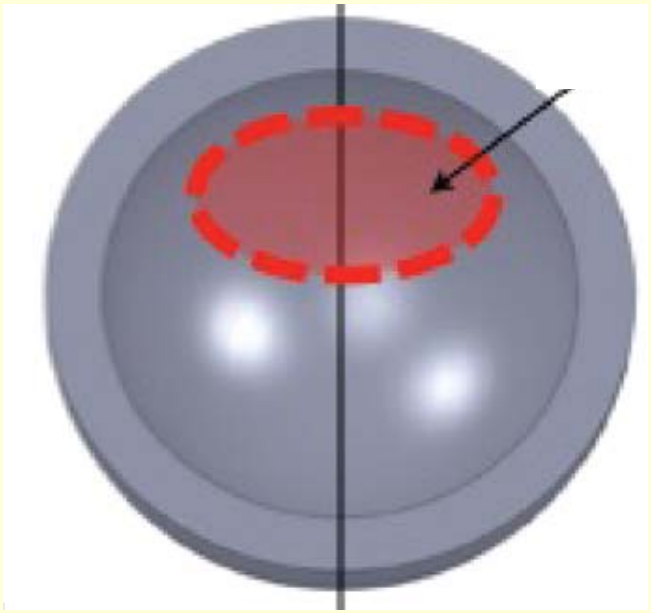




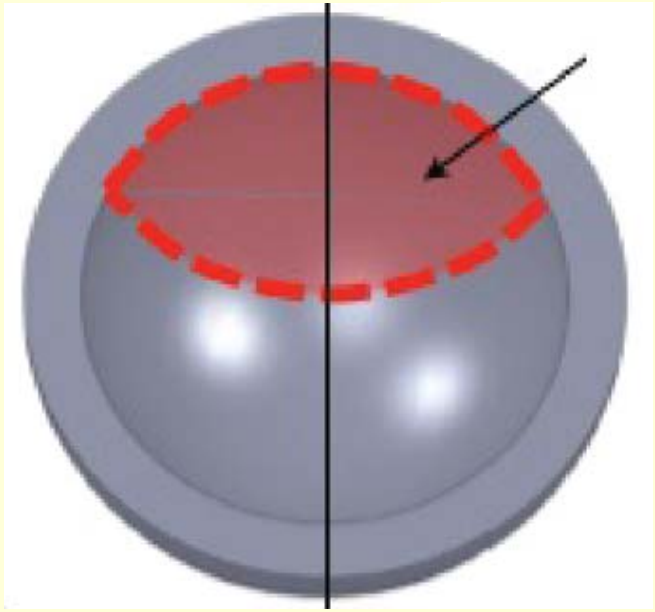
Edge Wear

Matthies et al, “Retrieval analysis of 240 MoM hip components, comparing modular THR with hip resurfacing,” JBJS[Br] 2011;93-B:307-14.

Why Simulators Don't Match the Retrievals?



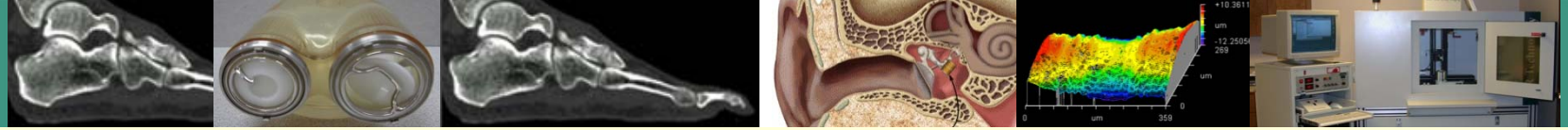
Non Edge Worn Cup



Edge Worn Cup

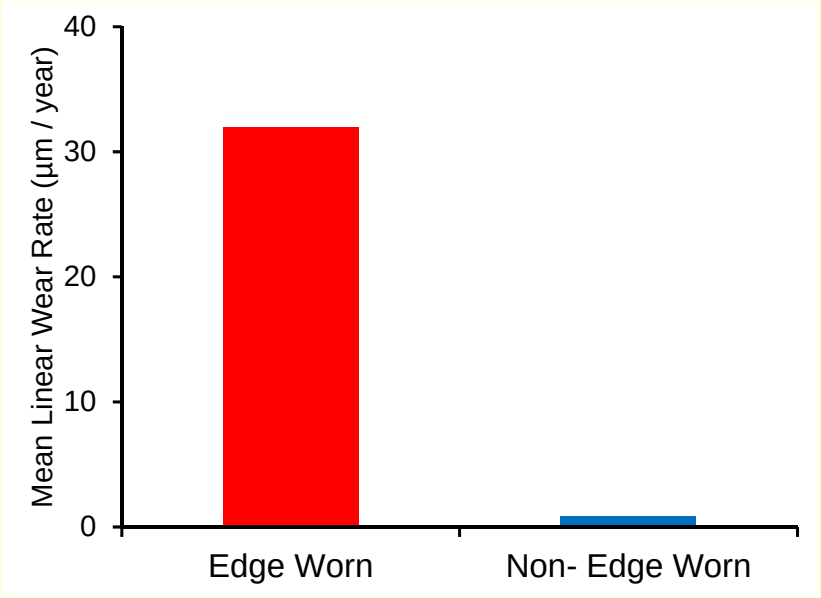
Edge Wear – The pattern of wear observed in acetabular cups in which the maximum depth of the wear scar occurs at the cup rim and progressively deceases along a path from the cup rim to the pole

Matthies et al, "Retrieval analysis of 240 MoM hip components, comparing modular THR with hip resurfacing," JBJS[Br] 2011;93-B:307-14.

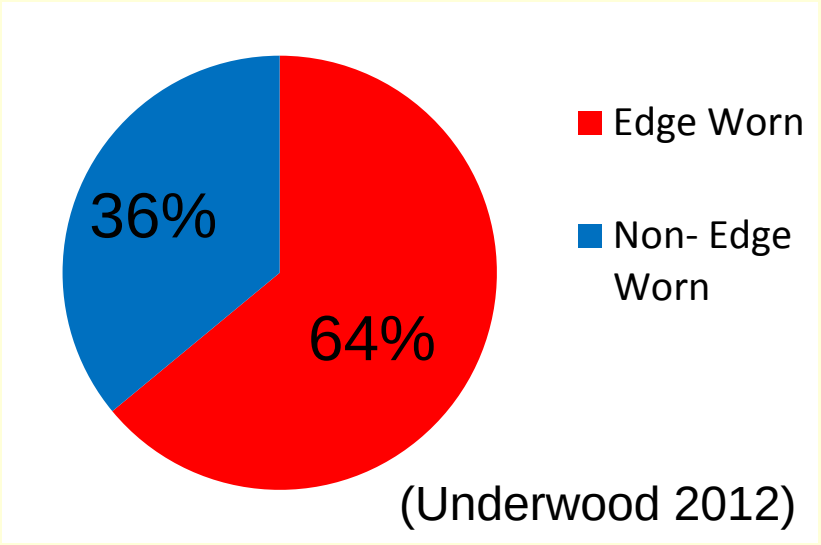


Edge Wear

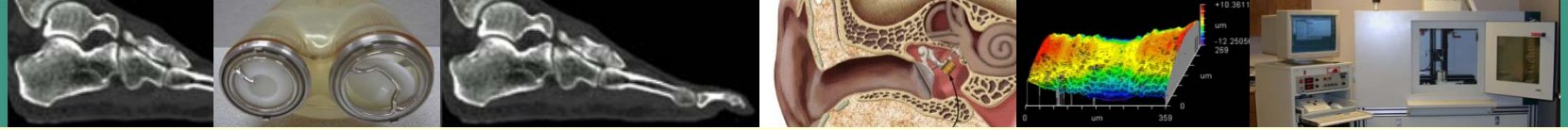
Elevated Wear Rate



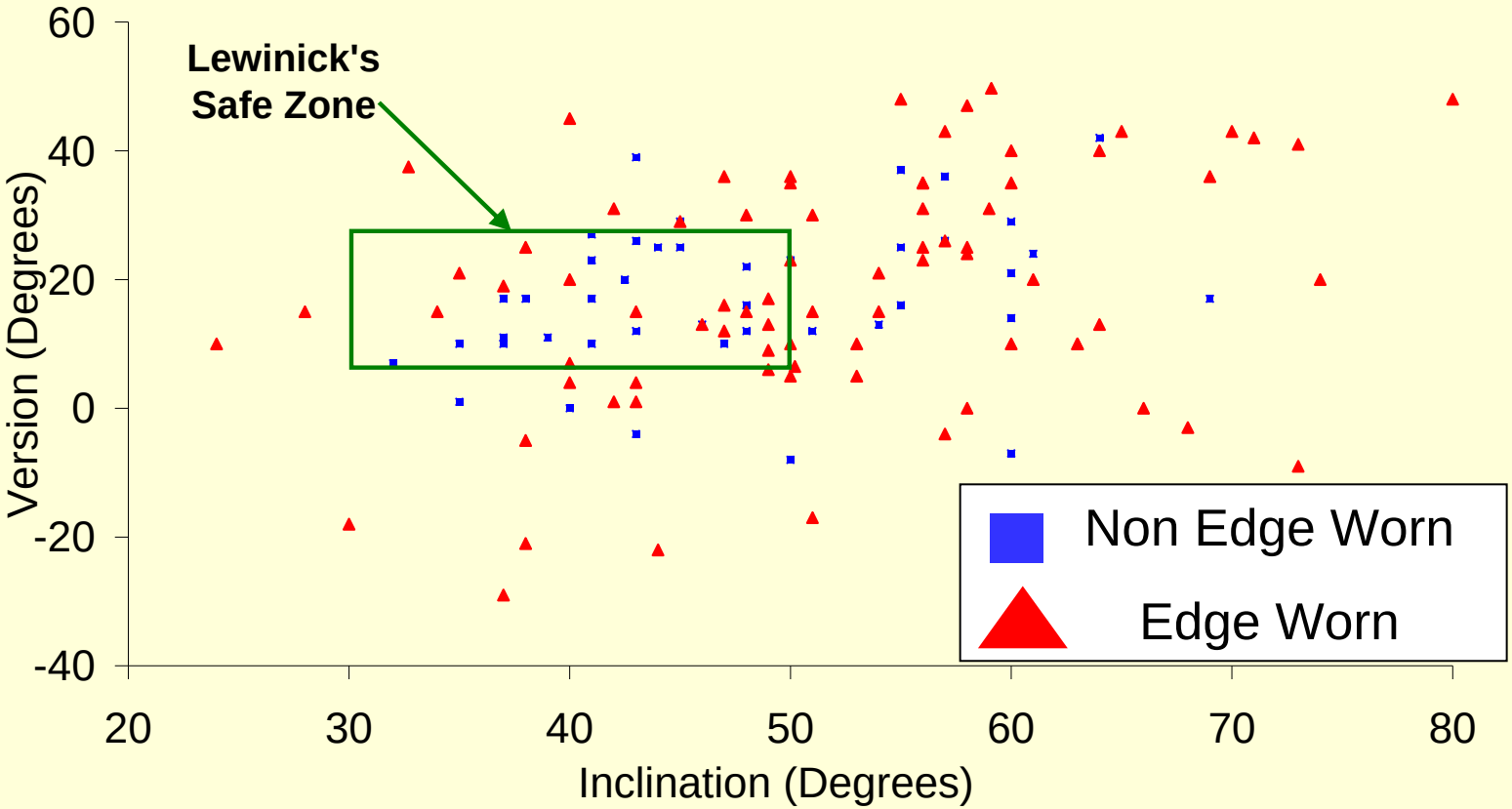
High Incidence of Edge Wear



Underwood et al, “Edge loading in metal-on-metal hips: low clearance is a new risk factor,” Proc. IMechE Part H 2012 226(3) 217–226

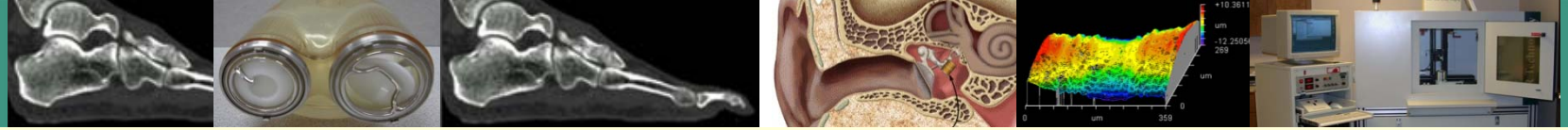


Acetabular Position vs Edge Wear

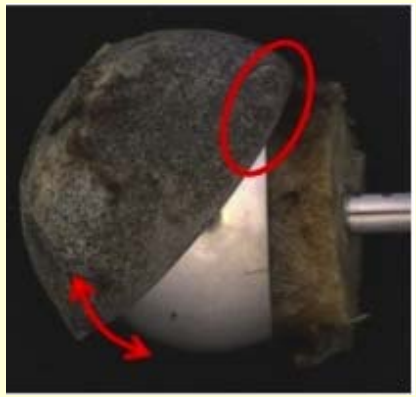


Edge wear occurs at all positions

Underwood et al, “What Are The mechanisms of Edge Loading In MoM Hips? A study of 400 Explanted Hip Components” 2011 ORS Annual Meeting

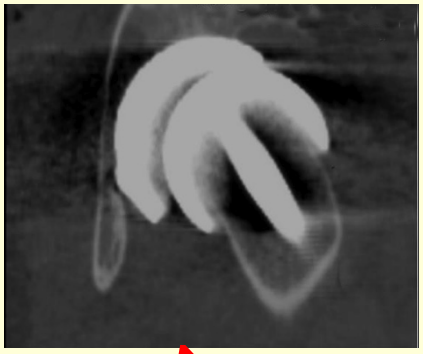


Three Causes of Edge Wear



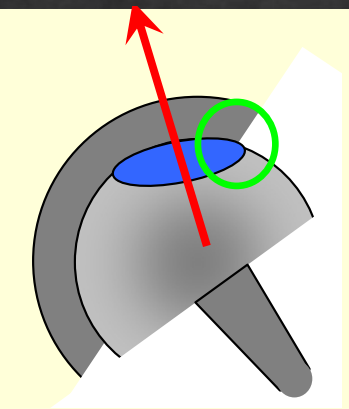
(Matthies 2011)

Impingement



(Underwood 2011a)

Micro Separation



(Underwood 2011b)

Edge loading

Matthies et al, “Retrieval analysis of 240 MoM hip components, comparing modular THR with hip resurfacing,” JBJS[Br] 2011;93-B:307-14.
Underwood et al, “What Are The mechanisms of Edge Loading In MoM Hips? A study of 400 Explanted Hip Components” 2011 ORS Annual Meeting
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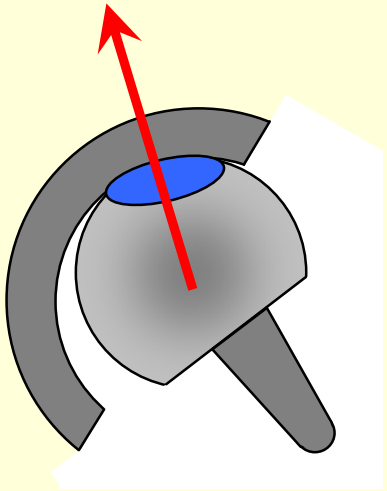
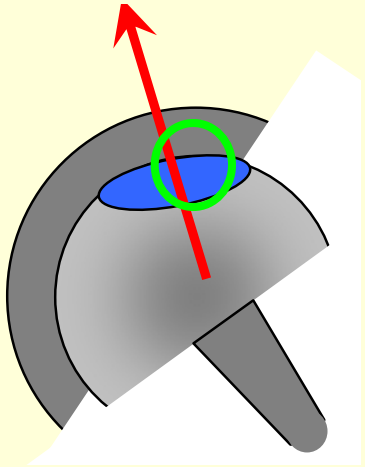
Edge Loading



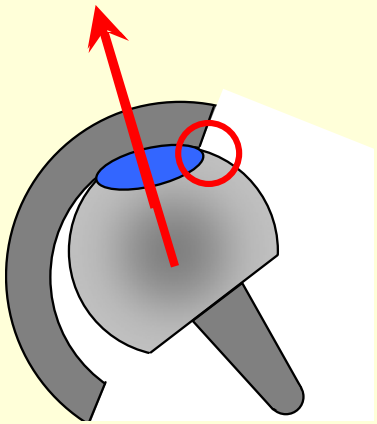
Schematic Diagram of Well Functioning Hip

Schematic Diagram of Edge Loaded Hip

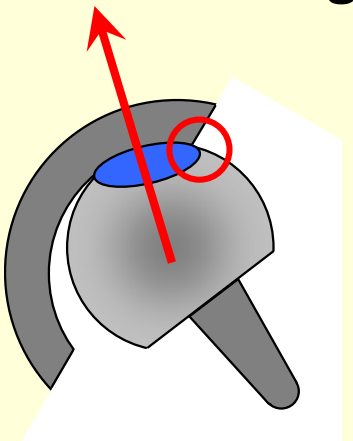


- Edge loading occurs when contact patch extends over cup rim
- Large increase in local contact pressure at cup rim
- Break down of boundary lubricant film leads to increased wear

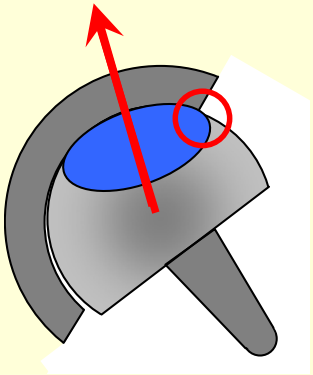
Steep Inclination



Reduced Coverage



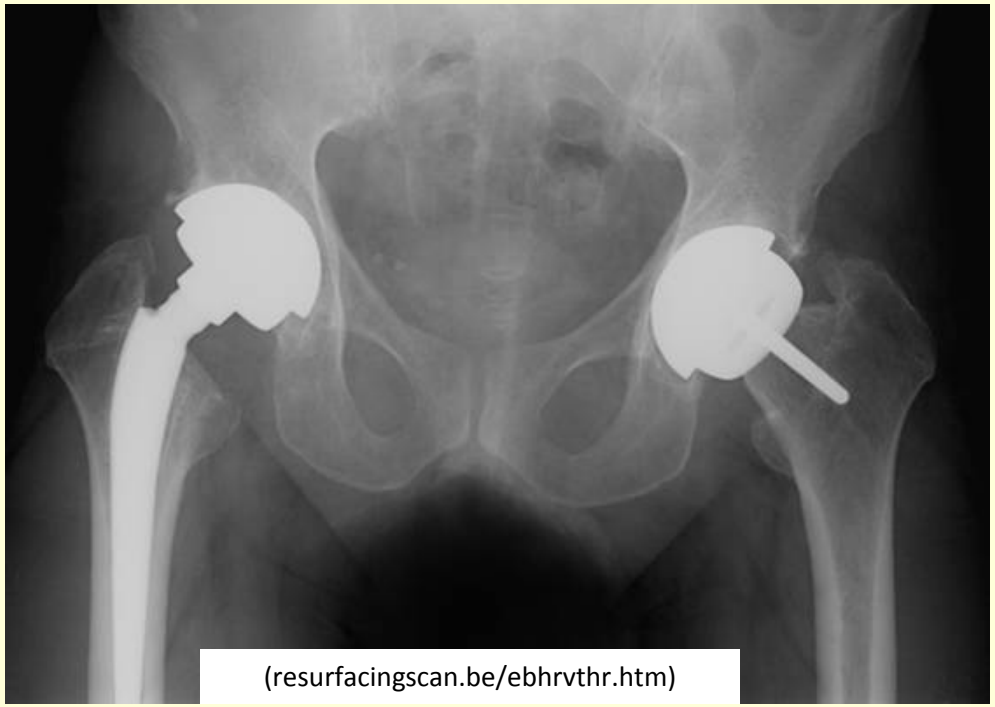
Reduced Clearance



Modular vs Resurfacing MoM Hips

Elevated revision rates reported for modular hips

- UK NJR 2010 7.8% modular, 6.3% resurfacing revision rate at 5 years
- Langton 2011 48.8% modular, 25% resurfacing revision rate at six years



(resurfacingscan.be/ebhrvthr.htm)

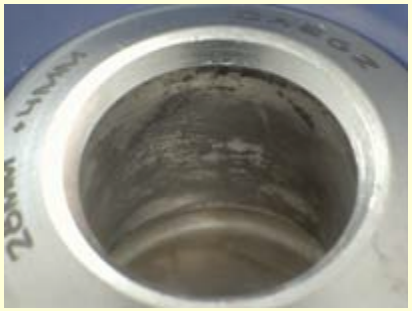
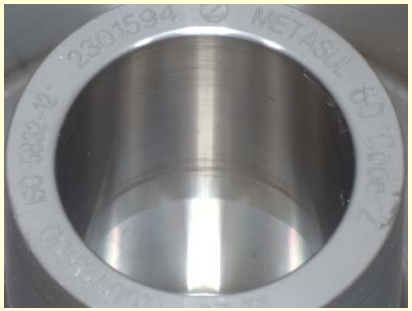
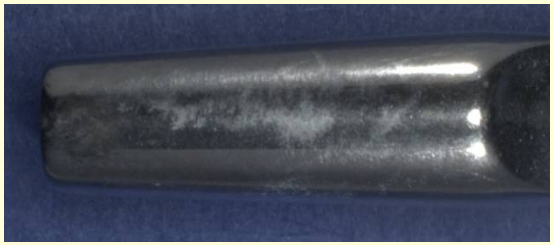
Langton et al, “Accelerating failure rate of the ASR total hip Replacement,” J Bone Joint Surg [Br] 2011;93-B:1011-16.

Taper Corrosion is Not New

Goldberg observed “moderate to severe” taper corrosion in 42% of retrieved M-PE hips with dissimilar metals

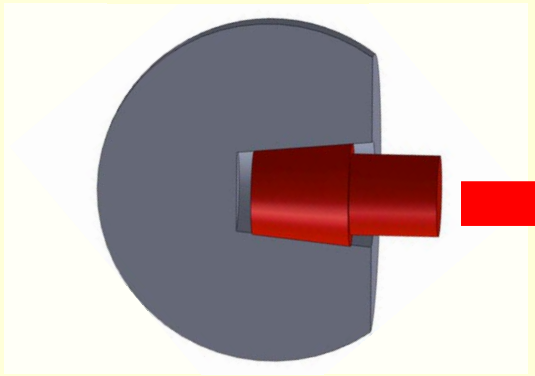


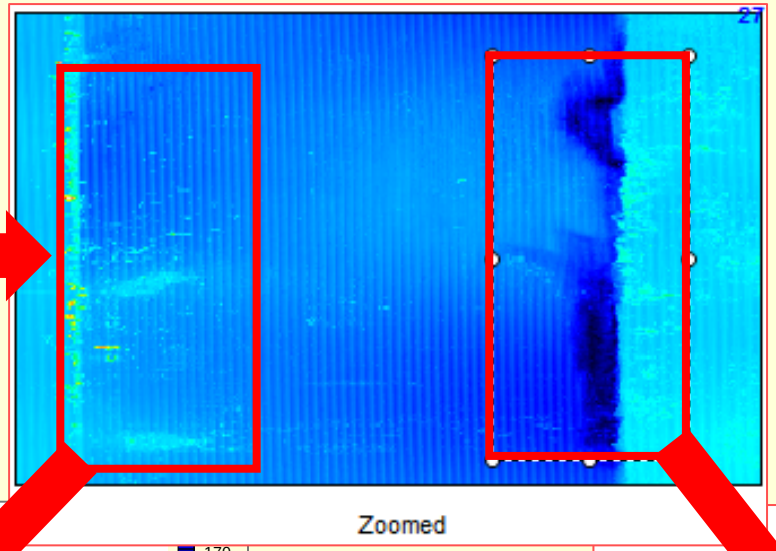


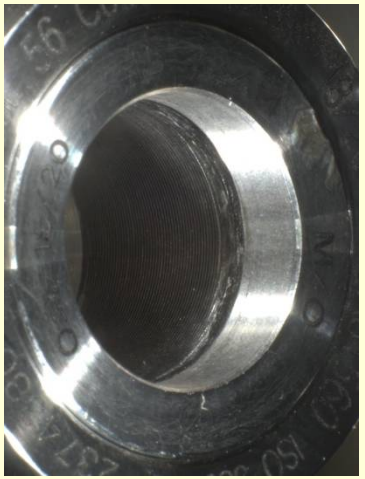




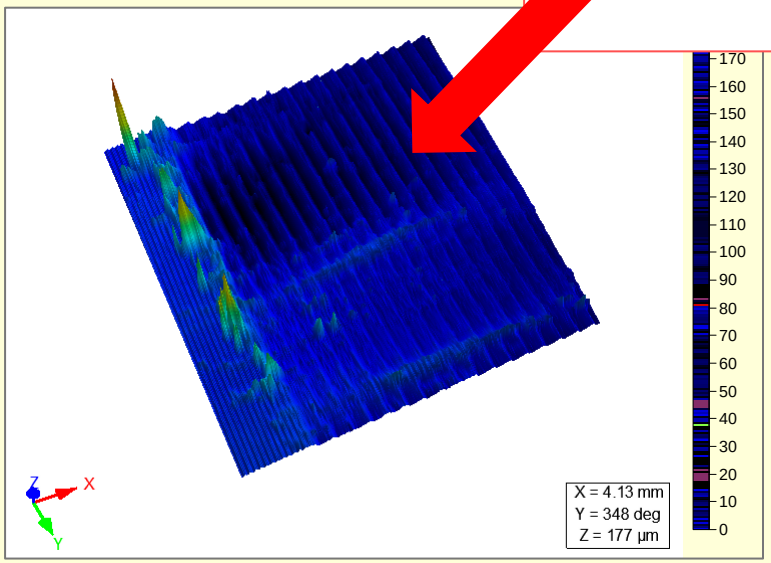

[1]Goldberg et al, “A multicenter retrieval study of the taper interfaces of modular hip prostheses,” CORR. 2002;401:149.

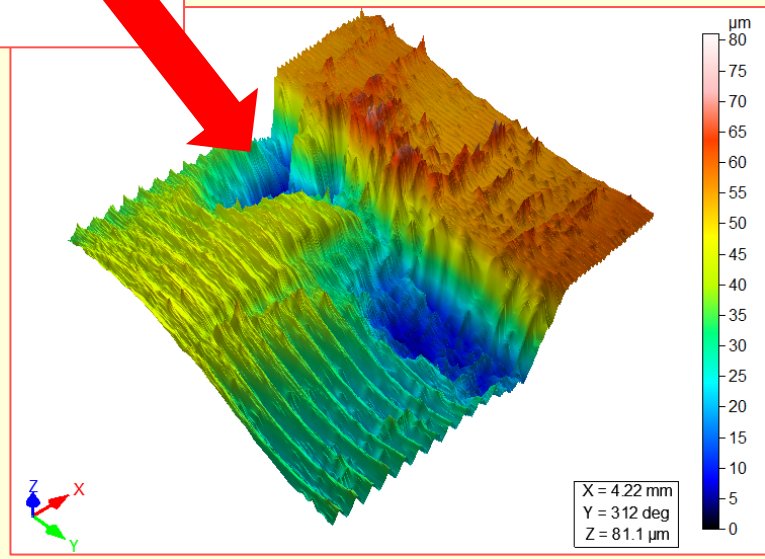
Maps of Head Corrosion

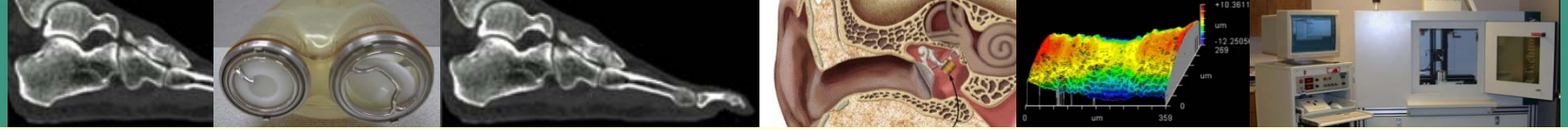












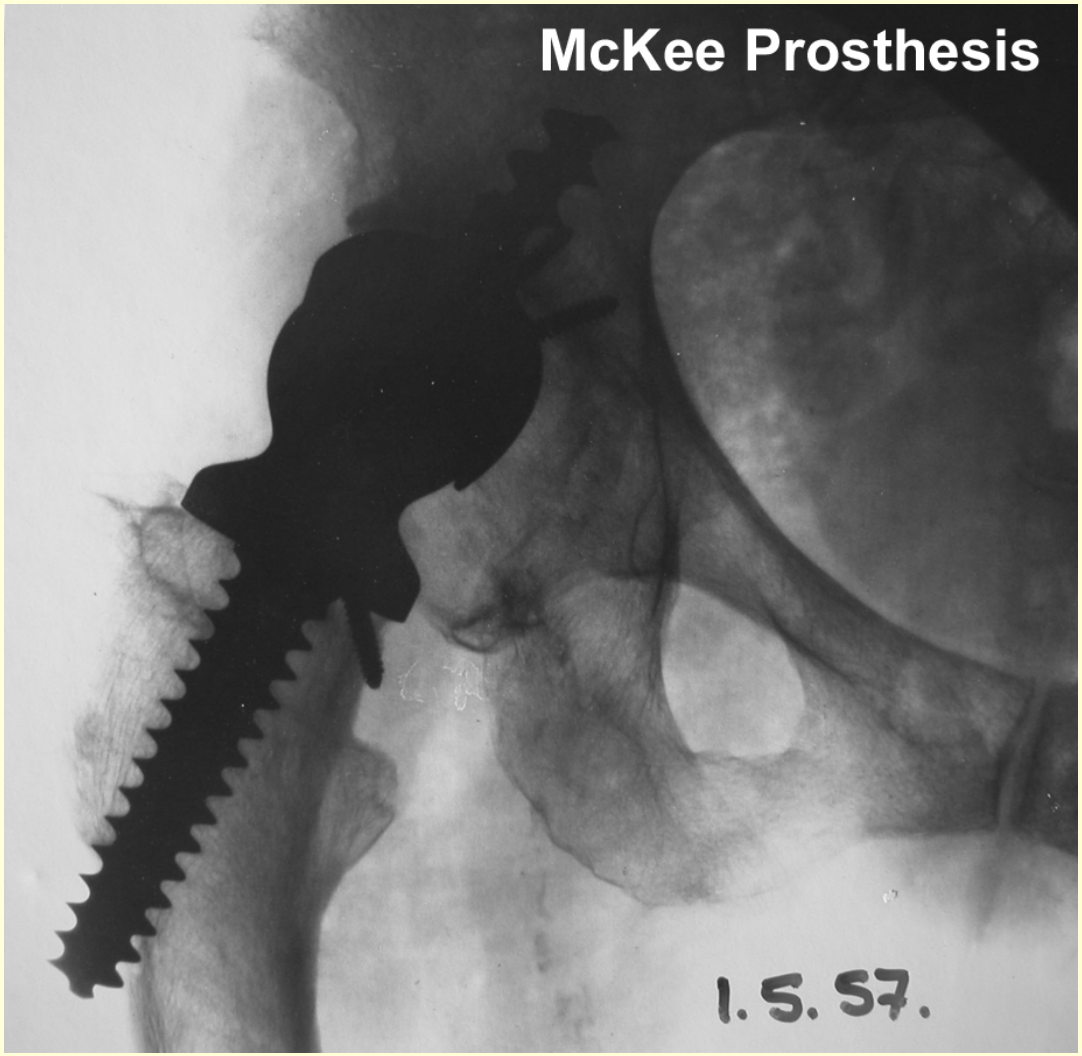
Why is Taper Corrosion a MOM Issue?

Proposed theories:

- **Langton 2011** – “splayed open by mechanical forces”
- **Gilbert 1993** – “mechanically assisted crevice corrosion”
- **Jacobs 1998** – Key variables: Metallurgical processing, tolerances, surface processing, selection of materials

Langton et al, “Accelerating failure rate of the ASR total hip Replacement,” J Bone Joint Surg [Br] 2011;93-B:1011-16.
Gilbert, “In vivo corrosion of modular hip prosthesis components in mixed and similar metal combinations.” J. Biomedical Materials Research, 1993, 27:1533 - 1544
Jacobs, “Current Concepts Review - Corrosion of Metal Orthopaedic Implants,” J Bone Joint Surg Am. 1998;80:268-82.

Summary: MOM Bearings are Not New

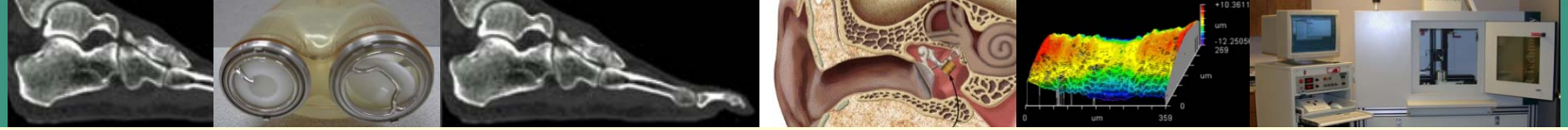


Summary: Bearing Mechanics

Tribology theory and in-vitro testing predicted low wear rates

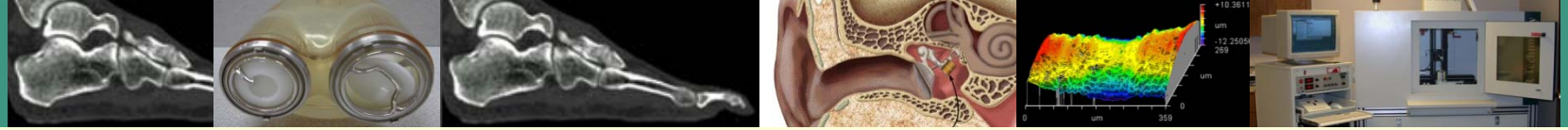
for MoM THA and resurfacings

Observations from certain retrieved MOM components do not support low wear hypothesis



Summary: MOM Device Failure Modes

- **Resurfacing** – Femoral neck thinning, fracture
- **Resurfacing and THA** – Elevated wear, edge wear
- **THA** – Taper corrosion, “trunnionosis”



Questions?

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